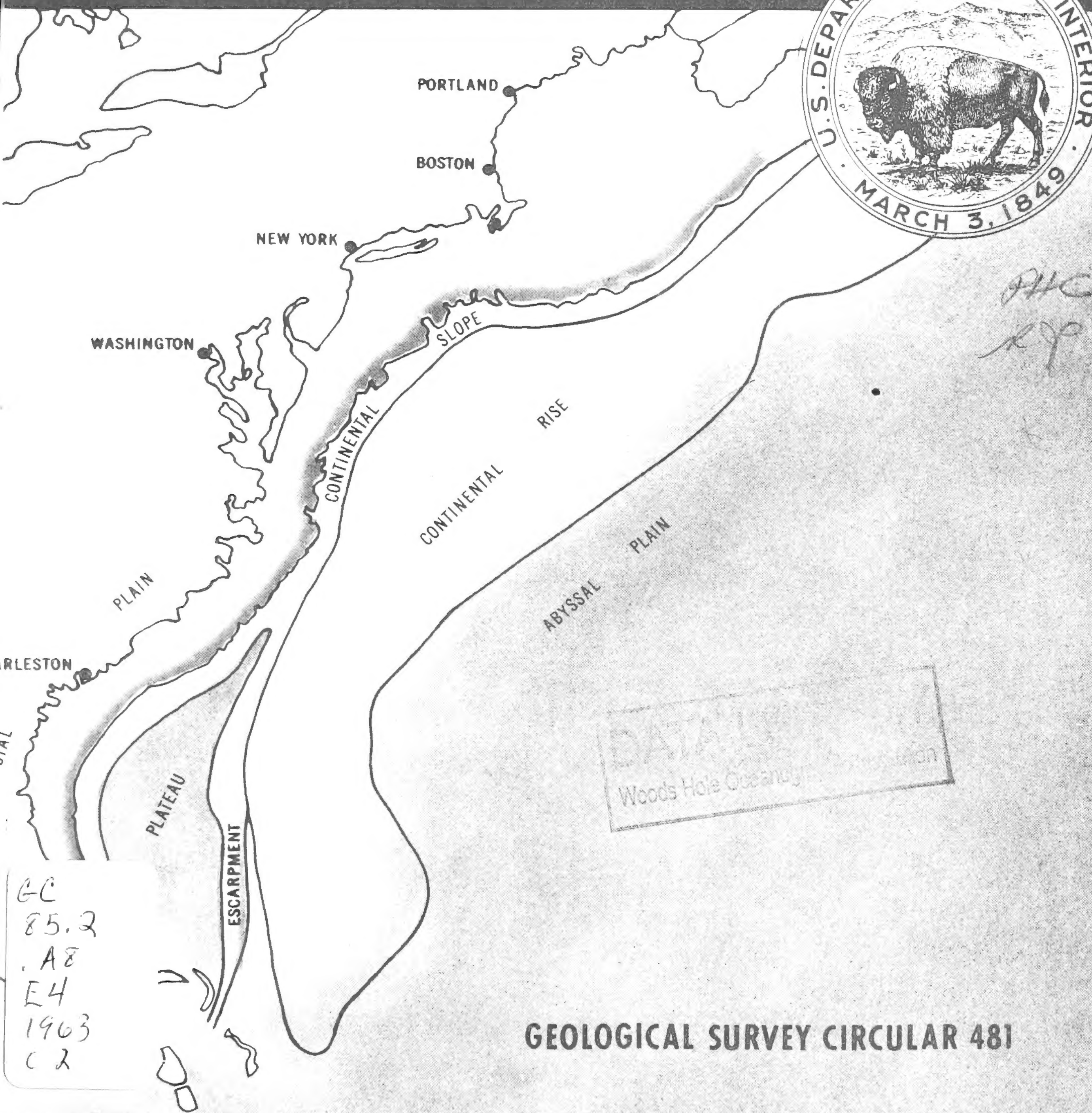
The Atlantic Continental Shelf and Slope A Program for Study



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THE ATLANTIC CONTINENTAL SHELF AND SLOPE, A PROGRAM FOR STUDY

K. O. Emery and John S. Schlee

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Frontispiece.-The research vessel <u>Gosnold</u> to be used for the geological investigation

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By K. O. Emery and John S. Schlee

INTRODUCTION

For many years the work of land geologist has stopped at the water's edge and that of marine geologists started at the same line. This division of interests came about partly because of the differences in geologic tools needed in the two environments, and partly through limitations in charters of organizations sponsoring the geologic work. Future progress in both environments will be sped by cooperative studies of continental margins. To geologists, these margins are significant because they are areas of great crustal mobility and may, therefore, contain the key to our understanding of the growth, and perhaps of the origin, of continents. Most sedimentary rocks that geologists study on land were formed in a shallow marine environment. If we are to evaluate the many factors such as source areas, composition, climate, transporting agents, and diagenesis that have molded the lithified end product, we must first discover the relationships between unconsolidated sediments and their shallow-water marine environments. Moreover, within the strata of many continental margins are structural and stratigraphic traps containing petroleum, and a thorough study of the margins may lead to discovery of additional traps.

In 1962, the Congress authorized a program in marine geology by the U.S. Geological Survey, and the Survey in turn entered into an agreement with Woods Hole Oceanographic Institution for a five-year joint investigation of the Continental Shelf and slope off the Atlantic coast of the United States. The Survey provides the financial support for the work, and scientists from both organizations are engaged in the study. The interests and abilities of the two organizations complement each other in this study. Several other organizations are also cooperating in certain aspects of the work; chief among these are the Bureau of Commercial Fisheries, which is processing benthic biological samples, and the Coast and Geodetic Survey, which is supplying smooth sheets of soundings taken by its many ships in the past, and during the course of the investigation. Still other organizations, mostly universities, are involved through their interests in special problems in such fields as taxonomy, chemistry, and and oceanographic training.

The area of the study extends from the border between Maine and Canada to the southern tip of Florida, a distance of about 2,500 km (see cover). It was chosen because of the probable continuity of strata from land to sea floor, and because some of the strata now exposed in outcrops on land were originally deposited under conditions probably similar to those now existing on the nearby sea floor.

FACILITIES

The research vessel for work at sea is a recently converted small Army freighter (Frontispiece), renamed Gosnold in honor of a sea captain who explored the region near Woods Hole in 1602. She is steel hulled, 30 m long, 6.4-m beam, 2.5-m draft, and of 250 gross tonnage. Diesel-powered (275 h.p.) with a variable-pitch propeller, she cruises at 13 km/hour but can also idle near zero speed. Fuel, water, and food capacities permit a 3,000-km cruising range, well in excess of the maximum range needed for the work. Bunking and other facilities are adequate for 15 persons. Approximately 100 days per year will be spent at sea; cruises will be about one month long and spaced a month or two apart.

1/ Woods Hole Oceanographic Institution, Woods Hole, Mass.

2/ U.S. Geological Survey, Woods Hole, Mass.

Navigation equipment includes gyrocompass and pelorus, automatic pilot, radar, Loran a, Loran C, and radio direction-finder. Three winches are arranged to work over the port side. For light high-speed work in shallow depths, a bathythermograph winch carrying 300 m of 4-mm stainless steel cable is used. Light deep-water work is done with a hydrographic winch carrying 6,000 m of 6-mm stainless steel cable. The heavy work will be handled with a trawl winch having 3,000 m of 12-mm nontwist cable of 13-tons breaking strength. To help handle heavy gear on board and overside, an articulated crane capable of lifting nearly one ton at its maximum extension of 6 m is situated near the middle of the main working deck. Most of the navigational and other electronic equipment is housed in a laboratory just below and forward of the bridge. Sample processing, chemical analyses, and other work are conducted in a portable van fastened to the deck just forward of the electronics laboratory. Several such vans belong to the different groups that will use Gosnold for their studies; each van, modified to a particular project's needs, can be hoisted aboard for each cruise to replace a van previously used by another group.

Supporting the ship's work are laboratories ashore, comprising an area of about 300 sq m for this program. The laboratories are well equipped with drafting facilities and map enlargers for study of topography, and with balances, sieves, settling tubes and cylinders, chemical apparatus, microscopes, X-ray, pH meters, and spectrophotometer for studies of sediments and rocks. In addition, the Woods Hole Oceanographic Institution has available a digital computer, salinometers, photographic and drafting facilities, electronic and machine shops, and a large file of unpublished information relating to coastal and off-shore waters. There are also available for consultation many workers at Woods Hole who possess special knowledge and experience in water characteristics, marine biology, and shoreline geology. The Geological Survey support services include map-making facilities, extensive collections of foraminifera and rocks, and radiocarbon dating and analytical chemical laboratories.

The study is being conducted by both Woods Hole Oceanographic Institution and the U.S. Geological Survey; scientists from both organizations are participating jointly. In the first year's activity existing data have been compiled, and new information from Gosnold cruises has been gathered and organized. The men involved in the study and their areas of responsibility are as follows:

- K. O. Emery, WHOI, scientist in charge of the study
- Donald J. Casey, USGS, river discharge and general sediments
- T. G. Gibson, USGS, micropaleontologist
- John C. Hathaway, USGS, X-ray and mineralogy
- Jobst Hülsemann, WHOI, general sediment chemistry
- R. M. Pratt, WHOI, lithology and topography
- John S. Schlee, USGS, Project Chief, stratigraphy and texture of sediments
- A. R. Tagg, USGS, sedimentology and mineralogy
- James V. A. Trumbull, USGS, coarse fractions and sediment texture
- Elazar Uchupi, WHOI, underwater topography and areal sediment mapping

Still to be added to the staff are a geophysicist, a geochemist, and a hydrologist.

PROGRAMS OF STUDY

Several kinds of geological information are to be obtained. To visualize the shelf and slope and to interpret Recent and Pleistocene geologic history, studies of topography and sediments are apt to be most rewarding. For pre-Pleistocene history, studies of lithology and structure contribute more. Tools and procedures for each of these fields of investigation differ both aboard ship and in the laboratory ashore.

Topography

Existing data on the topography of the Continental Shelf and continental slope come mainly from pre-1940 surveys by the U.S. Coast and Geodetic Survey. Some of these data (those which relate to the area between Massachusetts and North Carolina) were contoured and published by Veatch and Smith in 1939. Soundings by the Coast and Geodetic Survey and others from Lamont Geological Observatory and from the Navy Oceanographic Office served as the basis for a chart of the North Atlantic, including the Atlantic coastal margin, drawn by Heezen, Tharp, and Ewing (1959). Several more detailed charts of smaller areas have been made, but because of their local nature, these charts are not summarized here.

The Continental Shelf, about 2,500 km long, slopes outward from shore to the shelf-break at a depth which increases from about 50 meters off Florida to 120 meters off New England. The average width of the shelf is about 170 km, but

it ranges from less than 15 km off Florida to 500 km in the Gulf of Maine. The total area is about 510,000 sq km, of which nearly half is in the Gulf of Maine (for simplicity considered here as Continental Shelf). The surface of the Continental Shelf is a plain made somewhat irregular by glacial features in the Gulf of Maine by numerous submarine valleys, most of which only indent the shelf-break, by submerged wave-cut cliffs along most of its length, and by sand waves on Georges Bank and elsewhere (fig. 1).

Beyond the shelf break is a complex array of of continental slope, marginal plateau, and continental rise. The continental slope is steep (averaging 5°), and it descends to between 900 and 3,000 m. The average width is about 50 km and the area is about 150,000 sq km. Along most of its length, the continental slope is cut by submarine canyons. Benches, believed to have been produced by outcrops of resistant strata, occur along part of its length.

At the base of the continental slope is a broad apron, the continental rise. Much of the shallower part may be of structural origin, but the deeper part is probably a fan of debris deposited by turbidity currents. At its toe is an abyssal plain 5,000 to 5,500 m deep. The average width of the continental slope, marginal plateau, and continental rise between the shelf-break and the 5,000-m contour is 550 km, and the total area is about 1,400,000 sq km.

Contour charts of the Continental Shelf and slope are being prepared from most existing soundings; the charts will be contoured at 10-m intervals on the shelf and at 200-m intervals on the slope. The results of new surveys by the Coast and Geodetic Survey will be incorporated as they become available. In addition, sounding lines will be run about 18 km apart with the Precision Depth Recorder (which records in meters) aboard Gosnold during the course of sampling operations and in certain small areas where detailed studies of topography are desired. The contour charts will serve as base maps for other studies. Profiles obtained aboard Gosnold will supplement contours in providing a basis for Physiographic studies which should include delineation of areas shaped by different erosion and depositional agents, the positions of ancient shorelines of glacially lowered sea levels, and the extent of postglacial warping, as well as the perennial inferences about submarine canyons.

Sediments

Sediments of the Continental Shelf have been studied over a long period of time. Stetson

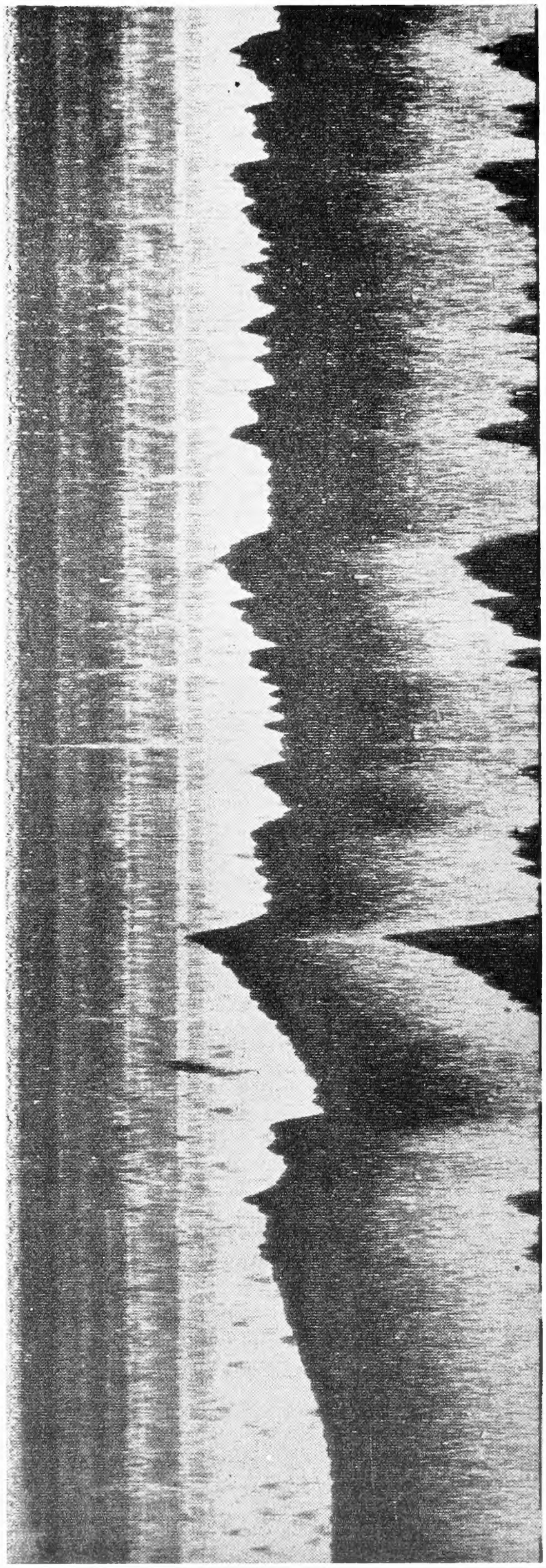

Figure 1.-Profile made with a precision echo sounder across sand waves on the continental shelf near Cape Cod

(1938) examined sediments along widely spaced traverses of the entire shelf. Shepard and Cohee (1936) analyzed many closely spaced samples off New York and Connecticut. The only modern study, and one that also overlaps on to the continental slope, is that of Moore and Gorsline (1960) on the area off southeastern United States. Reconnaissance study of sediments beyond the Continental Shelf has been made by the Lamont Geological Observatory and reported in a series of papers culminating in a summary paper by Ericson, Ewing, Wollin, and Heezen (1961). Many other studies have been made of sediments in estuaries and on beaches, but all are on local scale and unrelated.

Sediment will be collected as short-core or grab samples (fig. 2) about 18 km apart on lines about 18 km apart across the Continental Shelf. Adherence to a grid will not be strict, because allowance must be made for variations of sediment related to topographic features. At the approximate spacing of one sample per 350 sq km, a total of about 1,500 samples would be obtained. Probably about 2,000 samples will be obtained in order to portray more accurately certain local variations. A fine start has been provided by a suite of about 300 samples collected on such a grid spacing in the Gulf of Maine; these were obtained during 1959-61 by the Bureau of Commercial Fisheries in an effort to relate fish populations to sediment characteristics (Wigley, 1961). Laboratory studies will be made of texture carbonate, organic carbon, and nitrogen contents and of mineralogy, including clays and coarse fractions. These parameters are usually sufficient to determine the origin of sediments. Sediments on the continental slope to be investigated will be obtained by taking several hundred cores with the piston corer (fig. 3). These cores will allow study of the distribution of calcium carbonate and organic matter with depth, as well as changes in pore-water chemistry and rates of deposition.

The coarse grid of sediment sampling can be considered good reconnaissance, and it will certainly allow the delineation of areas of glacial, organic, authigenic, residual, relict, and modern detrital sediments (Emery, 1960, p. 198-208), and establish a framework for more-detailed studies of the shelf, including sediments of the past.

Lithology

Rocks cropping out on the Continental Shelf and in the submarine canyons were dredged by Stetson (1949), particularly in the region between Massachusetts and Virginia. Little rock sampling has been done elsewhere on the shelf. The best places for dredging are, of course, the walls of canyons, the shelf-break, and the face of the steeper parts of the continental slope (fig. 4). Stetson's work will be extended and detail added with possibly 300 well-distributed dredgings made from Gosnold. Additional rock samples may come from cores--both incidental and intentional. Cores have the advantage over dredgings of being more precise in depth and position, but the disadvantage of being less representative of an area and less certain of success. Eventually, some offshore drilling will be done to confirm interpretations derived from outcrops and from geophysical work.

Preparation and preliminary investigation of the rock samples will be undertaken at Woods Hole, in addition to the sorting and identification of most rock types in the predominantly igneous and metamorphic pebbles and boulders of glacial till and ice rafting. Final identification and correlation of sedimentary rocks in place will be made mostly or largely at the Geological Survey in Washington, where the staff is familiar with the lithology of the adjacent land, and where type rock samples and representative fossils collected from outcrops during many years are available. Also, the Geological Survey is making a compilation of Coastal Plain subsurface stratigraphy.

The identification and study of rock specimens obtained from the sea floor may provide new information on the continuity or facies changes of strata well known in outcrop on land. Strata cropping out on land, particularly the Tertiary strata, consist largely of nonmarine sediments, but probably these grade seaward into their marine equivalents.

Structure

Many refraction and reflection seismic lines have been run across the Continental Shelf by Ewing and associates at Lamont Geological Observatory (a representative report is one by Drake, Ewing, and Sutton, 1959). Some have been carried farther seaward by the same group and by Hersey, Bunce, Wyrick, and Dietz (1959) of the Woods Hole Oceanographic Institution.

Other kinds of geophysical data are needed more urgently at present. Chief of these are continuous reflection seismic profiles (fig. 5) of the type obtained by sparker and thumper. Such seismic profiling is planned for Gosnold to be done mostly at night. The records should reveal the thickness and distribution of postgla-

Figure 2.-Large Campbell grab made by Logan Smith of Wilmington, California

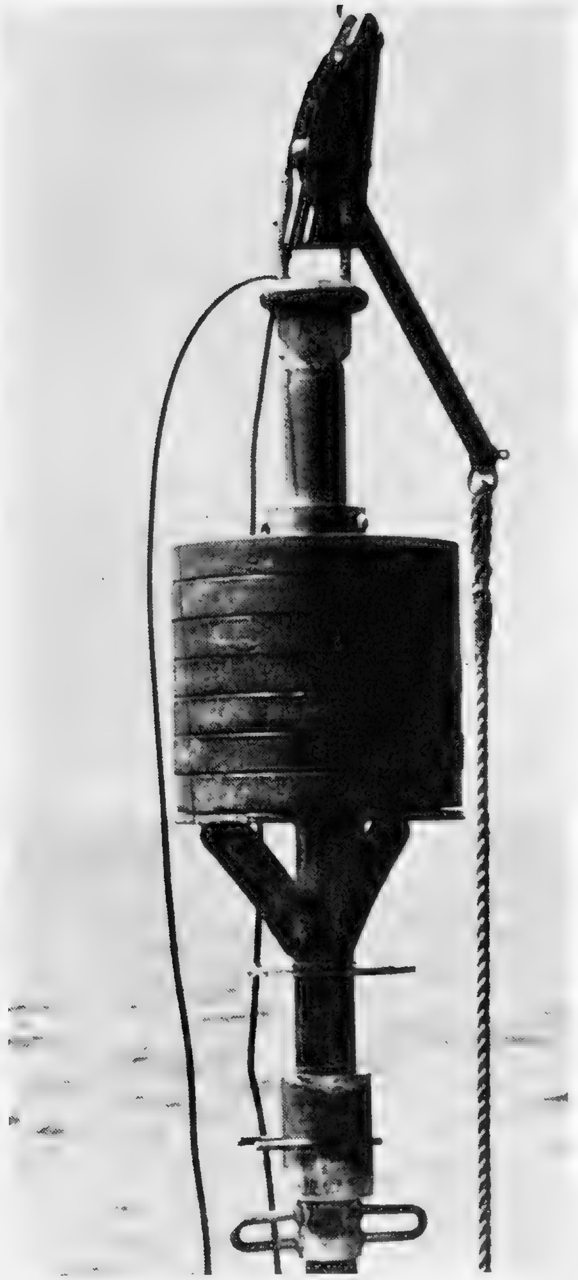

Figure 3.-Piston corer overside and to be lowered to the bottom

cial deposits, the wave-erosion terraces beneath these deposits, and the presence of filled extensions of submarine canyons. The presence or absence of sediments mantling the continental slope, or extending from the shelf down the slope, are important criteria for estimating the relative roles played by erosion and deposition in forming the Continental Shelf and the slope. Even more important, the profiles should indicate the structural attitudes of the strata underlying the shelf; regional seaward dips are shown by many unpublished recordings, but probably folds and faults are present locally. It is expected that at the end of the five-year study the entire shelf and slope will be crossed by seismic profiles at intervals averaging perhaps 36 km.

Water

Data on characteristics of water above the Continental Shelf and slope are more abundant than in other fields of interest; and, so, water sampling will constitute but a minor part of the work. Among the studies which will be made are those on relationships of water movement to transportation of sediment and erosion of the bottom. Internal waves, particularly those of tidal period, are of considerable interest in this respect, and their proper study is best carried out by anchored buoys. Similarly, direct measurements of currents near the bottom may be related to other work now being done at Woods Hole, and to estuarine studies by the Geological Survey. Studies of sea level recorded at tide gages indicate that water discharged by rivers into the ocean accounts for seasonal and perhaps long-term changes of sea level. Chemical and energy relationships of this runoff may permit it to serve as a useful tracer for following water movements on the shelf. Plans are also being formed for the examination of the characteristics of interstitial water of the sediments in order to learn more of the methods by which early diagenesis of sediments occurs. Much of this chemical work will be done in association with R. M. Garrels and Raymond Siever of Harvard University.

Biology

Many of the surface sediments will be sampled with a large (250 kg) grab which recovers about 0.2 cubic meter of muddy sediment from an area of 0.6 square meter. Within the grab is mounted a camera which takes a photograph of the bottom just before the device touches bottom. Comparison of photograph and bottom sample has revealed interesting differences during preliminary work, and the photographs show attitudes and relationships of organisms difficult to infer from the disturbed condition in samples. As in previous work on the Pacific coast, the samples will be sieved in a shaker table on deck (fig. 6) to separate the organisms larger than about 1 mm in diameter from smaller organisms. On return to shore, the preserved organisms will be turned over to the Bureau of Commercial Fisheries for determination of associations and of biomasses of

(Continued on p. 10)

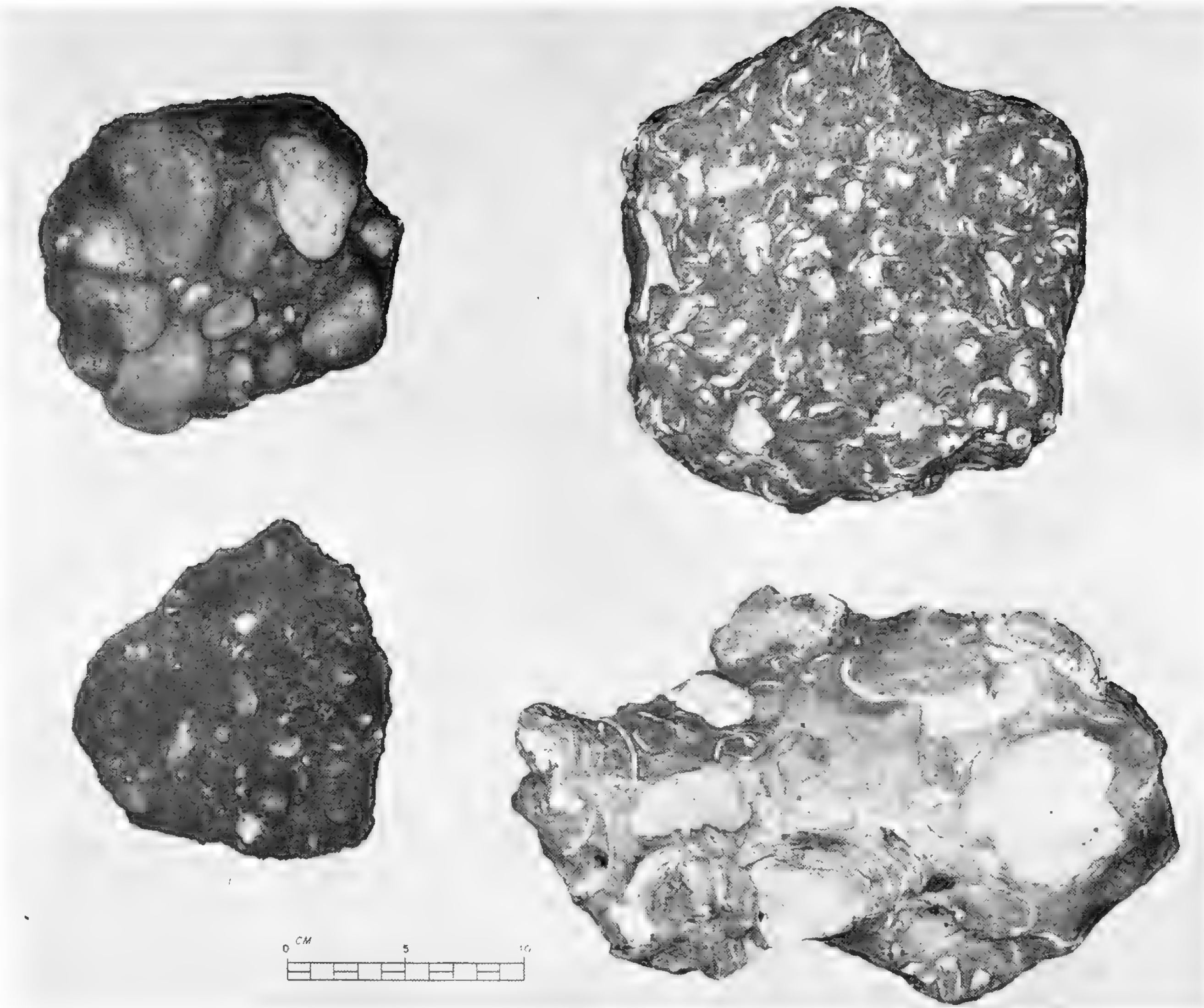

Figure 4.-Blocks of conglomerate and fossiliferous sandstone dredged from the top of the northern slope of Georges Bank

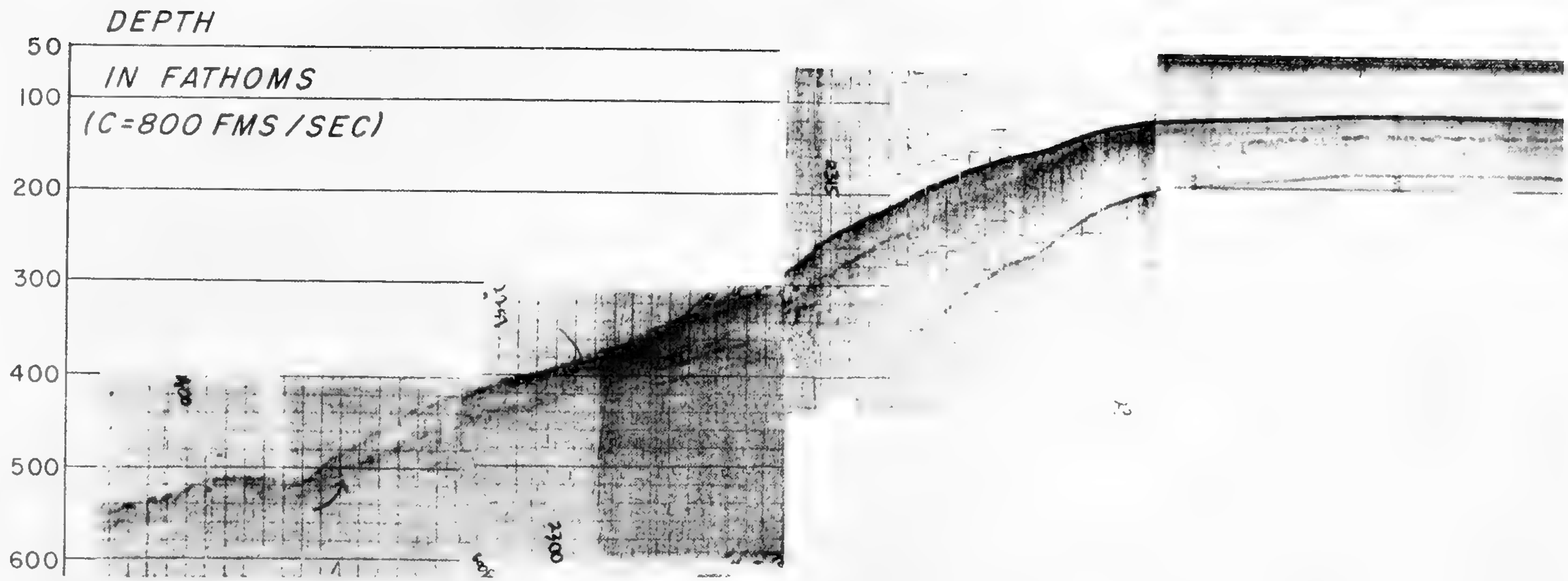

Figure 5.-Typical record made by a continuous seismic profiler.

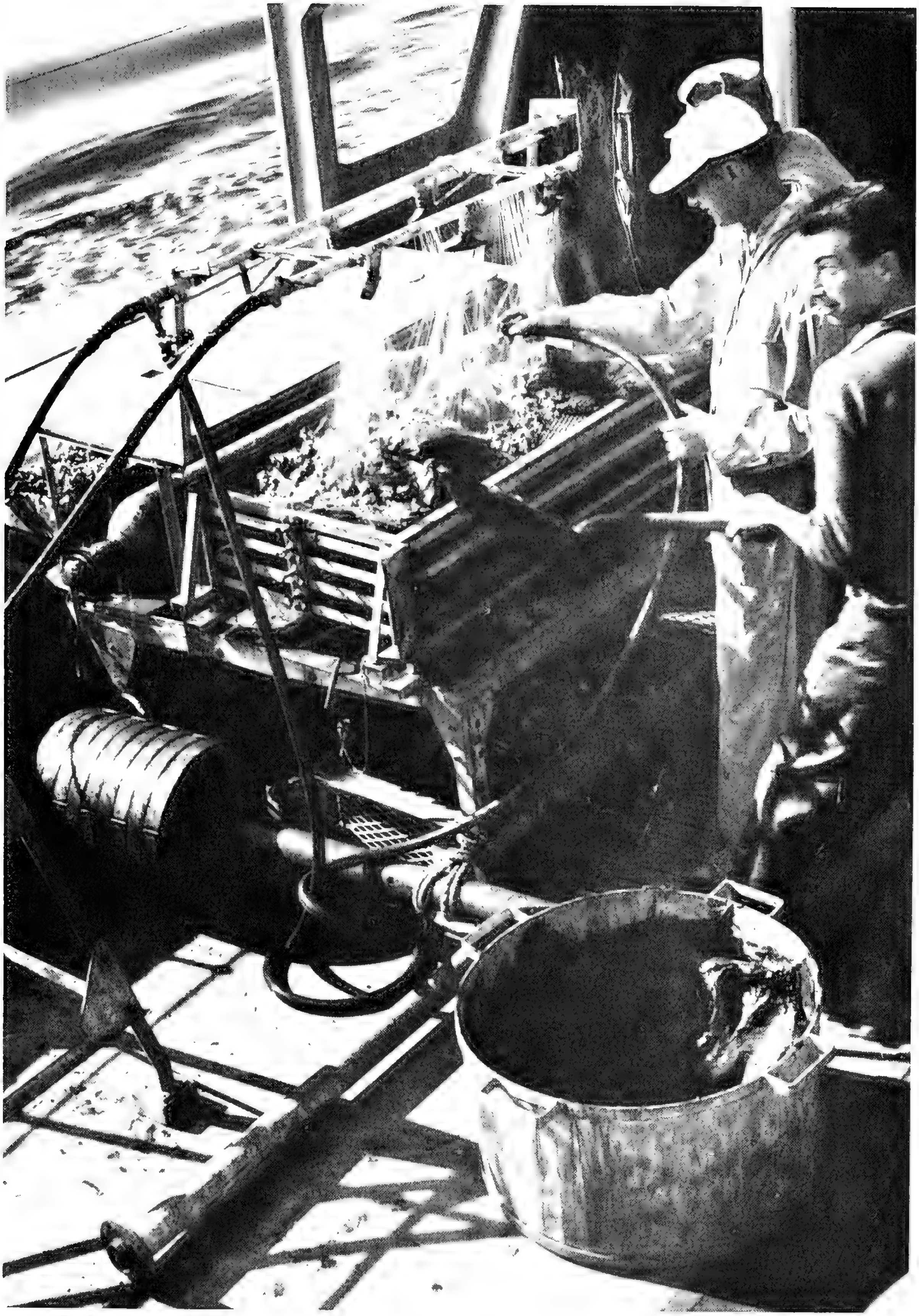

Figure 6.-Shaker table used to sieve sediment samples collected with the large Campbell grab

major categories of organisms by R. L. Wigley and Arthur S. Merrill. Geologic reasons for inclusion of this phase include: the need to determine the effects of mixing activities by benthic animals; the fact that a small to large percentage of the sediment consists of organic remains; and previously observed indications that points of escape of fresh water are marked by colonies of freshwater worms.

Some data on plankton and productivity to supplement existing information may be obtained through collaboration with biologists at Woods Hole Oceanographic Institution, who are chiefly concerned with these questions. This kind of information will be needed to interpret the distribution of organic matter in the sediments and to aid in the study of foraminiferal ecology.

BROAD ASPECTS OF THE PROJECT

Information exists about the Continental Shelf and slope in many parts of the world, but nowhere can it be considered very complete. General topography is known, but usually detailed knowledge is lacking; witness, for example, the much higher concentration of known submarine canyons in the best-sounded regions--United States, Europe, and Japan. The world distribution of submerged terraces is even less well known than are canyons, because terraces require better soundings. Although probably no new large canyons will be found on the Atlantic coast, it is likely that new soundings and seismic profiles will reveal the presence of and much about the nature of submarine terraces. This knowledge should stimulate interest in further investigation of the extent and depth of such terraces elsewhere in the world. Similarly, the presence or absence of a blanket of sediment which extends from the Continental Shelf down the continental slope will indicate whether or not this slope progrades by deposition. Such conclusions can be applied to other areas after a relatively small effort is spent on testing in these areas.

Local structures such as faults and folds can generally be expected to be associated with structures known on land. However, the great tectonism of many continental slopes suggests that other kinds of folds and faults may be associated with the outer Continental Shelf and the slope; such structures may be closely related, and found in this environment in many parts of the world. The deeper seated downfolds of crustal rocks beneath the Continental Shelf and slope off the Atlantic and Gulf coasts of the United States and off England may be a common characteristic of continental margins to be discovered elsewhere when adequate seismic studies are made.

Sediments on outer continental shelves and slopes have a family resemblance throughout the world, because modern detrital sediments generally have not yet covered those relict from glacially lowered sea levels. The same lack of cover by modern detrital sediments has permitted the accumulation of slowly deposited organic and authigenic sediments near the shelf break. Comparison of sediments on the Atlantic shelf with those of fairly well studied areas in the same latitudes off southern California and off the Asiatic coast (Niino and Emery, 1961) should provide evidence of the controls exerted by water temperature and salinity and by contributions from land. These inferences can subsequently be applied more certainly than in the past to estimation of facies control within ancient strata. Fortunately, the Atlantic Coastal Plain and Continental Shelf are underlain by Tertiary sedimentary rocks which were probably deposited in an environment somewhat similar to the existing one. Therefore, application of the knowledge gained from modern sediments can be applied directly to ancient strata.

In the same vein, sedimentary structures similar to those in modern sediments have been used by Potter and Glass (1958) to infer the environment of deposition in ancient sedimentary rocks. These structures are among the most obvious features of rock outcrops studied by land geologists. Not only have they been helpful in determining environments, but they also have aided in deducing the ancient geography. Similar sorts of structures will be encountered in the cores taken on the shelf and slope. Here we will have an opportunity to see what types of structures are indicative of different environments, through correlation with other properties such as type of benthic fauna present.

Studies of the types outlined above must be regional in extent even though based on widely spaced samples. Detailed studies of small areas cannot have the necessary breadth of land and sea-floor environments. The Atlantic Continental Shelf is sufficiently large for this general framework study, because it covers 20° of latitude and has an area equaling that of all the New England states plus New York and Pennsylvania, or 5 percent of the total United States. The continental slope, of course, has an additional large area, and the continental rise even more.

The labor of constructing a general environmental framework is such that many interesting

questions of diagenesis must be temporarily passed up or only sketchily investigated at first. Many of these process problems will be investigated as time and opportunity permit. Among these are questions of alteration of organic matter leading to petroleum, the changes of interstitial waters with time and depth of burial, and migration of sand waves in formation of sheet sands. Clearly, most process problems can best be investigated when a sufficient level of understanding is reached concerning origin, transportation, and deposition of the particular source materials, including their enclosing sediments. This means that the topography and water movements must be known far better than at present.

Lastly, we may expect that the results of the general study will have considerable application to future recovery of oil and gas and to mining of such sea-floor deposits as manganese and phosphorite. Certainly we cannot now foresee the full benefits of a study which is the first of its kind and which is now just beginning.

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